APPENDIX C, ESA TECHNICAL EVALUATION OF JPL CASSINI SOLAR CONCEPT (Hassan 1996)

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COPIES:	D. Dale / P		
OUR REF.:	PY/1.0/IIII/6339/sp		
SUBJECT:	LILT Solar Cells		

Attached please find a memo from the Head of Power Conversion Division (XP) on the above subject .

I thrust that this closes the related action item satisfactorily.

Best regards,

H. Hassan

European Space Agency
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ESTEC

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memorandum

Ref: XP- **1612-dos** **Date:** 31st August 1996 Reg. 40

Your Ref.:

To: H. Hassan (PY)

From: D. M. O'Sullivan (XP)

CC: K. Bogus (XPG), C. Signorini (XPG), J. Haines (XPM

Subject: Assessment of the JPL system study related to the possible use of photovoltaic arrays for the CASSINI mission

Following evaluations of recently provided JPL documentation in the ESTEC Power and Energy Conversion Division, please find attached two relevant assessments.

It is evident from the attached assessments that although ESA is currently proposing to use photovoltaic solar arrays supporting Low Intensity, Low Illumination (LILI) solar cells for the ROSETTA cometary encounter (3.25 AU) spacecraft, such an approach for the more power demanding, much deeper space (9.3 AU) and poorly known Saturn radiation environment of the CASSINI mission, is impractical in respect of its launcher capability and the scientific requirement for a rapid body orientation ability.

As a result we concur with the reviewed JPL system level study which shows a mass and configuration impact for the currently defined 837 watt CASSINI mission, which would be prohibitive for the programme.

Although a new generation of ultrathin LILT soar cells could potentially offer a solution and produce a lower mass impact than the 1396 kg addressed by JPL in the study such solar cells have not yet been developed.

As a result of the attached deliberations it can be concluded that as of this point in time, LILT solar cells (including those developed by ESA) are not a viable power source alternative for the presently defined CASSINI mission of NASA.

D. M. O'Sullivan

Head of Power and Energy Conversion Division (XP)

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memorandum

Ref: XP- **1611-jh** **Date:** 31st August 1996

Your Ref.:

To: H. Hassan (PY) via D. O'Sullivan (XP

From: J.E. Haines (XPM)

CC: K. Bogus (XPG), C. Signorini (XPG)

Subject: Assessment of the JPL system study related to the possible use of photovoltaic arrays supporting Low Intensity, Low Illumination GaAs and Si solar cells for the CASSINI mission. (Appendix D of the Cassini EIS Supporting Studies Vol.2)

Following your request to assess the overall system/power system aspects of the JPL study on the possibility of using GaAs and LILT solar cells for satisfying the CASSINI mission, please find the result of my own evaluation:

1) General

It is evident that the work presented in Appendix D demonstrates a comprehensive study on the part of JPL into the potential of applying new solar cell technologies to the CASSINI mission. In particular the study addresses the possibility of applying:

i) High efficiency silicon (Si) solar cells with defined Low Intensity, Low Temperature (LILT) performance.

and

ii) Gallium Arsenide (GaAs) solar cells with defined Low Intensity, Low Illumination (LILT) performance

to the CASSINI mission.

It must of course be noted that although the ESA ROSETTA spacecraft programme is intended to be operated with LILT solar cells up to a maximum sun distance of 5.2 AU (with full science operations only needed up to a sun distance of 3.25 AU), CASSINI has the distinct disadvantage of having to operate in Saturn orbit, this resulting in a full spacecraft performance requirement at a sun distance ranging between 9 AU and 9.3 AU.

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In terms of solar intensity this results in CASSINI receiving only:

$[(1/9.3)^2/1]$ - 0.0115 (1.15 %) of the solar insulation as compared to an earth orbit

2) Solar Cell Technologies and Performances

An assessment regarding the solar cell performances evaluated during the course of the JPL study contained in memorandum K. Bogus to H. Hassan (XPG/KB/4796-1/mac) dated 4th July 1996.

The conclusions of this memorandum however were that JPL had presented a balanced and realistic picture with regard to the predicted performances of both the LILT Si and LILT GaAs solar cells evaluated during the course of this study.

3) System Level Aspects

In reviewing Appendix D it is apparent that an extensive assessment of the system level impacts of incorporating a suitable photovoltaic array onto the CASSINI spacecraft has been conducted with the mass and cost implications being addressed in detail. The specific performances assumed for the solar array area and consequent mass, its incorporation onto the spacecraft and integration with the on-board electrical power system appear to be realistic figures.

The only two technical points where it is considered the assessment has been excessively <u>optimistic</u> is ;

i) In regard to the fact that the introduction of the peak power tracker for main power bus regulation (in lieu of an RTG shunt regulator), will result in an additional 5% - 10% throughput power loss within this ‘serial’ type regulator.

This will be reflected as a 5% to 10% <u>increase</u> in the power required from the photovoltaic array.

ii) In regard to the implications for spacecraft attitude control where for the LILT GaAs solar cell case the predicted increase in the CASSINI launch (wet) mass is from its current level of 5.630 tonnes to 7.026 tonnes (6023 kg of core spacecraft and 1003 kg of deployed, and highly flexible solar arrays).

Although the JPL study addressed the implication of a much reduced maneuver rate capability for a solar powered CASSINI, it can be foreseen that the resultant configuration where the deployed, flexible, solar array is a significant proportion of the overall spacecraft mass, will result in the definition of highly complex attitude control laws and an extensive supporting verification test programme.

This mass ratio between the core spacecraft and the deployed solar array panels will of course get worse at end of mission life when the 3130 kg of on-board liquid propellant is depleted, the core spacecraft mass then reducing to only 2893 kg.

4) Conclusions

The detailed assessment conducted by JPL into the possibility of powering the CASSINI mission with photovoltaic array and energy storage batteries has resulted in the identification of a projected mass increase of 1.396 tonnes for a LILT GaAs solution to 1.977 tonnes for a LILT Si solution. Both of these deltas result in a total spacecraft mass which is outside of the capability of the current best launcher option (Titan IV/Centaur) for the CASSINI mission.

As a result of reviewing the system level evaluation conducted by JPL on can only support their present conclusion, that replacement of the three currently baselined Radio-isotope Thermal Electric Generators (RTGs) by a photovoltaic power source utilizing ‘start of the art’ technology is impractical for the currently defined CASSINI/HUYGENS mission to Saturn and its moon Titan.

J. E. Haines

MEMO: XPG/KB/4796-1/mac 4-7-1996

FROM: K. Bogus (XPG)

TO: H. Hassan (PY)

cc.: XP, C. Signorini (XPC)

Subj.: LILT Solar Cells and JPL's CASSINI Study

Attached please find a draft of the XPG-assessment of the JPL-memo on "European LILT solar cells and Cassini" for your perusal. Following the incorporation of changes which you might propose, this could be send to JPL as planned.

It is essential to take note of the following comments and remarks in order to read the assessment in the proper perspective:

[1] The JPL-memo is a revision of on earlier JPL note by the same author, P. Stella who is a well-known solar cell expert at JPL. This previous note is not accessible in XPG.

[2] The JPL-memo mentions a Cassini solar array (system) analysi s performed previously at JPL which apparently studied the mission-impact of replacing RTG's by a solar array using US-solar cells. This report is also not available and outside the scope of our comments.

[3] The comments made on European LILT cells developed under ESA contract are limited to the component level. No solar array has been designed yet with these cells and statements on array subsystem level are therefore of somewhat hypothetical nature. Further comments on system level aspects could possibly be generated by systems engineers of the ROSETTA team.

ESTEC, 4-07-1996

ESTEC-Solar Generator Technology Section Comments to the JPL-MEMO on "European LILT Solar Cells and Cassini" (P. Stella/Ref. nr. 342-PSRE-95-119 Rev. A/date: 26-06-96)

[1] General Remarks:

Data available at ESTEC on European LILT-solar cells are limited to ROSETTA-type applications, i.e. up to about 6 A.U. and down to temperatures of -150 °C. Therefore, data for the CASSINI mission have to be based on extrapolations with their associated uncertainties. This also applies to the particle radiation damage which for CASSINI is much more severe that for ROSETTA.

The approach chose for these extrapolations in the JPL-memo appears generally sound and the general results obtained are considered as balanced and without over-pessimistic bias.

[2] Detailed Comments:

[2.1] The LILT-silicon cell efficiency reported by ESTEC at 5.8 A.U. and -150 degrees C is 24%-26% whereas the JPL-memo quotes 22%-24%. These lower values are considered as realistic in the context of the memo considering the fact that the ESTEC reported data are peak values of laboratory-made devices and not mass-production devices on the one hand and also the possibly detrimental effects of temperature and lower sun intensity at 9.2 A.U..

[2.2] Similar comments apply for the efficiency of the GaAs-on-GaAs cells.

[2.3] The assumptions on cell mass and thickness for CASSINI-type solar arrays are considered as non-pessimistic for the silicon and GaAs-Ge-LILT-cells developed so far. It is noted that a reduction of cell mass might be feasible by developing LILT-GaAs cells in ultrathin substrate-free configurations as demonstrated by recent developments for 1 A.U. applications. Admittedly, the mass reduction on array level would be limited since the solar cell mass is only one of several array-mass determining factors. Moreover, ultrathin LILT cells have not yet been developed.

JPL's assumptions on array mass can not be verified at ESTEC since they are based on a specific JPL-subsystem design. However, there is no reason to assume that the JPL data as used in the previous CASSINI solar array study, are over-pessimistic.

[2.4] The statements made in the JPL-memo on radiation damage of LILT cells in the CASSINI radiation environment indicate correctly the general trends but are fairly vague. From the data available at ESTEC the general trends as stated are confirmed and no data with higher accuracy can be provided since (a) the available measured data of low-temperature radiation damage in LILT cells are not giving a complete picture yet and (b) the CASSINI radiation environment is not known in detail and has not been analyzed at ESTEC.

[3] Conclusion:

The statements made in the JPL-memo referring to European LILT-solar cells result in an overall balanced and realistic picture of the LILT development results. The numerous uncertainties appearing in the memo are unavoidable since the LILT-development in Europe is oriented towards the ROSETTA-application which is very different from the CASSINI case. It is doubtful whether more accurate CASSINI-specific LILT solar cell data would lead to a radically different assessment regarding array mass and area.

MEMO

342-PSRE-95-119 **REV.A**

To: Sandra Dawson
From: Paul Stella Paul Stella
Subject: European LILT silicon cells and Cassini
Date: June 26, 1996

Revision Items: This memo has been revised to include recent data on the European LILT solar cells and on integral bypass diodes for solar cells. The diodes that are now undergoing development would fit beneath the solar cells and not utilize additional array area. Although it is not clear that these would be compatible with ultra-thin solar cells, it will be assumed that they will be suitable. This most recent data indicates that the initial Cassini array study results are still valid, i.e., that any such array will be prohibitively massive.

References:

1. “Low Temperature Irradiation Damages in Silicon Solar-Cells" by Isamu Nashiyama, 11th International Symposium on Space Technology and Science, Tokyo, Japan, July, 1975,
2. "Development of Advanced Si and Ga As Solar Cells for Interplanetary Missions", by G. Strobl et al, Proceedings of the 14th Space Photovoltaic Research and Technology Conference, October, 1995, NASA Conference Publication 10180

The Cassini solar array analysis was reviewed and updated to account for improved silicon cell LILT performance using published data on the European research cells. This was done using data from the December, 1994, World Photovoltaic Conference in Hawaii. The analysis that we performed attempted to determine a cell efficiency for operation at 9.2 AU. Data presented above extends their measurements to 5.8 AU and requires an extrapolation for use at 9.2 AU. It is noted from their data that their is a small fall off in efficiency when moving from 3 AU to 5.8 AU. This would suggest that 9.2 AU efficiencies would be even lower. However, it was decided to use the 5.8 AU values, as measured, as an optimistic estimate. Their measured cell efficiencies have been in the 22-24+% range at 5.8 AU, depending on the type of cell measured. They now are working with three (3) cell types, silicon, GaAs/GaAs, and GaAs/Ge (for the latter two cells the second entry is the base substrate material. The GaAs/Ge cell has been added since this memo was originally prepared. This was done to reduce costs and also to increase cell strength since pure GaAs is extremely fragile. Ge (germanium) provides an improvement although it is still much more fragile than silicon. For this reason, the GaAs type cells must be limited to minimum thicknesses twice the thickness of the thinnest usable silicon cell. Since GaAs and Ge have more than twice the density of silicon, the thinnest GaAs cell is approximately four times the mass of the thinnest silicon cell. We assumed that actual production cell performances would average approximately 22% for use on Cassini. This reduction from the research results is observed for both existing silicon cells and GaAs/Ge cells and reflects the cell variations that exist in large production lots. At present, the existing process is more complex than for conventional space cell manufacture and a drop of an efficiency point is not unusual for reasonable production yields. Since a Cassini array would utilize a very large quantity of cells it would not be practical to "handpick" just the "highest" cells. This is especially true since a cell optimized for 9.2 AU, reduced grid line density, for example, would not be suitable for typical Earth orbiting missions.

The existing European LILT silicon cell is approximately 200 microns thick, appreciably greater than the 62 microns assumed in our existing Cassini analyses. Due to the complexity of their process and the need for accurate cell surface etching, it is expected that cell thickness reduction to this level would incur substantial handling and breakage problems. In fact, manufacturers of conventional cells have discouraged use of cells of this thin size due to extreme breakage. (It turns out that the use of a 200 micron silicon cell will have approximately the same array blanket areal mass density (Kg/meter^2) as the 85 micron thick GaAs/Ge cell used in the initial Cassini analysis). The approach undertaken in our "quick look" reassessment was to recalculate the GaAs/Ge array performance using the higher value of 22% efficiency obtained by the Europeans rather than the 18.3% value originally assumed for GaAs/Ge. (This basically simulated replacing the GaAs/Ge cell with the thicker European LILT silicon cell maintaining the array blanket areal mass density value.) The projected savings in array area would then be 20%, corresponding to the difference in cell efficiencies. It was assumed that the mass savings would be somewhat less, in the 10-15% range. There are two reasons for this. First, a large fraction of the lightweight deployable array mass is contained in area independent components such as deployment motors and latches/containment structures. Consequently, these masses would not change. Second, as in the case of silicon, it has proven difficult to manufacture ultra light solar cells without extreme breakage. For GaAs/ Ge, the minimum practical thickness is most likely 100-125 microns. For GaAs/As it would be even thicker, especially in view of the use of an ultra-low mass flexible substrate and ultra-thin coverglasses (50 microns). This is considered an optimistic evaluation.

At a first look it would seem that a cell mass savings could be achieved by using the LILT silicon cell which exhibits efficiencies at 5.8 AU comparable or better than the GaAs based cells. However, reasons why this is not expected to be the case are focussed primarily on cell radiation behavior. However, it is well known that silicon cells degrade more severely than GaAs cells. Data presented in reference two shows a substantial power loss for the silicon cells at radiation levels that are lower than presently anticipated for the Jupiter fly-bye. From the data it is estimated that the silicon cells will lose between 30 and 40% of their unirradiated efficiency during the severe fly-bye. Consequently it is likely that the a silicon array consisting of the LILT silicon cells would end up heavier than the GaAs array in order to compensate for the radiation induced power loss. As a final note, information (ref 1.) discovered in our literature search (B. Nesmith and P. Stella) indicates that cells irradiated at low temperature conditions, such as would be encountered at Jupiter, may suffer more severe degradation than cells subjected to the same irradiation at room temperature conditions. Inasmuch as the Cassini analysis has been conducted to date using room temperature laboratory radiation data it is likely that all solar array analyses have been using overly optimistic cell radiation assumptions. This can only be quantified by performing low temperature irradiations on the U. S. and European cells of interest.

Consequently, it is concluded that the use of European LILT cells on a Cassini array may provide some improvement in mass and area factors. However, due to the extreme requirements of this mission, the impact of these improvements is minimal and does not substantially change the basic conclusion regarding excessive array mass and area.

cc: C. Lewis
B. Nesmith
R. Wilcox

Cassini Mission
Final Supplemental Environmental Impact Statement